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TACTICAL NIGHT TERRAIN FLIGHT NAVIGATION

James A. Bynum and Garvin L. Holman

ARI FIELD UNIT AT FORT RUCKER, ALABAMA

U. S. Army

Research Institute for the Behavioral and Social Sciences

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This report documents two experiments which were conducted to determine the training required to improve tactical night terrain flight aircrew performance. These experiments sought, specifically, to identify critical factors which should be included in a program of instruction for tactical night terrain flight navigation training with unaided vision. In the first experiment a passive navigation task was used to establish an altitude which would provide adequate training with a safety margin, the types of terrain or → over

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other features which should be used for checkpoint identification, and the effect of daylight exposure to a route on subsequent navigation performance. Using Experiment I as a building block, Experiment II tested the effects on active navigation performance of light level, type of map, and order in which light level was experienced. Multiple step-wise linear regression was used to determine associations among the variables and provided an accounting of the variance attributable to each variable of interest. It was concluded that unaided vision navigation is possible at illumination levels as low as 2×10^{-4} foot candles. Instructional programs must consider restrictions to visibility, map type, proper preflight planning, adequate dark adaptation, a standardized intra-cockpit phraseology, and should use natural terrain features with vertical relief for checkpoint identification.

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Research Report 1226

TACTICAL NIGHT TERRAIN FLIGHT NAVIGATION

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Flight Training and
Aviator Selection

ARI Research Reports and Technical Reports are intended for sponsors of R&D tasks and for other research and military agencies. Any findings ready for implementation at the time of publication are presented in the last part of the Brief. Upon completion of a major phase of the task, formal recommendations for official action normally are conveyed to appropriate military agencies by briefing or Disposition Form.

FOREWORD

The Fort Rucker Field Unit of the Army Research Institute provides timely support to the US Army Aviation Center (USAAVNC) through research and development efforts to enhance aircrew performance in the tactical environment. One portion of these efforts has been directed toward improving aircrew skills in navigation at tactical terrain flight altitudes. Since 1973 the Army Research Institute has conducted studies concerned with the capabilities of average aviators and instructor pilots to fly at tactical terrain flight altitudes. The research efforts reported here are in response to Human Resource Need (HRN) 76-85, Aircrew Performance, which identified the need to determine training essential to improve night nap-of-the-earth (NOE) aircrew performance.

The entire program of aviation training research and development is responsive to the requirements of RDTE Project 2Q263743A772, Aircrew Performance Enhancement in the Tactical Environment. It is also responsive to the needs of the Director of Training Developments, USAAVNC, Fort Rucker, Alabama.

Joseph Zeidner

JOSEPH ZEIDNER
Technical Director

TACTICAL NIGHT TERRAIN FLIGHT NAVIGATION

BRIEF

Requirement:

To investigate the tactical night terrain flight navigation capabilities of pilots and to determine the kind of training and program content essential to enhance tactical night terrain flight aircrew performance.

Procedure:

Two experiments were conducted. In the first, students were flown in a passive navigation task in which each was required only to maintain orientation on a selected course. Data were compiled on terrain features, appropriate training altitudes, and effects of daylight exposure to routes. The second experiment tested the effects of light level, order of experiencing light level, and map type on active navigation performance.

Findings:

Tactical night terrain flight navigation was trainable; subjects could navigate with unaided vision in conditions as dark as 2×10^{-4} foot candles; dark adaptation was essential to good performance; map type was an important factor; and restrictions to visibility affected performance significantly.

Utilization of Findings:

These findings will be incorporated into a recommended program of instruction for tactical night terrain flight navigation training.

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Introduction

Army aviation experiences in Vietnam and the role of Army aviation in other potential conflicts has resulted in dramatic changes in the expected employment of Army aviation. Current Army doctrine (FM 1-1, Terrain Flying) has characterized the future battlefield as a high threat environment in which an enemy combat posture with sophisticated weapons and techniques will create a highly lethal situation with the intention of establishing control over territory and airspace contiguous to that territory. Army aviation elements are expected to operate as members of a combined arms team in a both nuclear and non-nuclear environments. These elements will be required to conduct both day and night missions in all weather conditions. Army aviation elements can expect enemy electronic warfare and must operate under conditions of radio silence. In addition, Army aviators might expect enemy tactical fixed wing aircraft and helicopters. To counter this threat, and to survive in the high threat environment, the Army aviation has elected to develop a tactic of terrain flying. Terrain flying involves flight close to the earth's surface, and includes the tactical application of low-level, contour, and nap-of-the-earth (NOE) flight techniques as appropriate to the enemy's capability to acquire, track, and engage the aircraft. Figure 1 illustrates the three techniques of terrain flying.

The actual employment of one of these three techniques, listed above, depends upon the mission to be accomplished. However, in any case, there are fundamental elements which are necessary to successfully conduct terrain flight. These include improved crew integration techniques, improved aircraft handling skills, and improved navigation skills. This research report amplifies the third of these elements, namely navigation.

Since by definition terrain flying is flight as close to the earth's surface as the conditions require, or will allow, new or unique requirements are placed on the aircrew at terrain flight altitudes. The range of sight, the field of view, and the perspective change dramatically for the pilot and navigator at these low altitudes. Army aviation experiences with terrain flight altitudes, particularly during the latter phases of the Vietnam conflict, pointed out the difficulties of navigation at these altitudes. In 1973, the Army's conference on Aircrew Performance in Army Aviation (1974) identified navigation as one area requiring major improvements. It was recognized then that major improvements were clearly needed in the ability of Army aircrews to navigate and maintain accurate geographic orientation. As stated in the conference executive summary: "The skills required for navigation and orientation at high altitude in a benign environment are virtually irrelevant in modern Army aviation. Army aviators must acquire a new set of skills involving accurate terrain analysis, precise pilotage in a highly restricted visual field, and valid map interpretation." As a direct

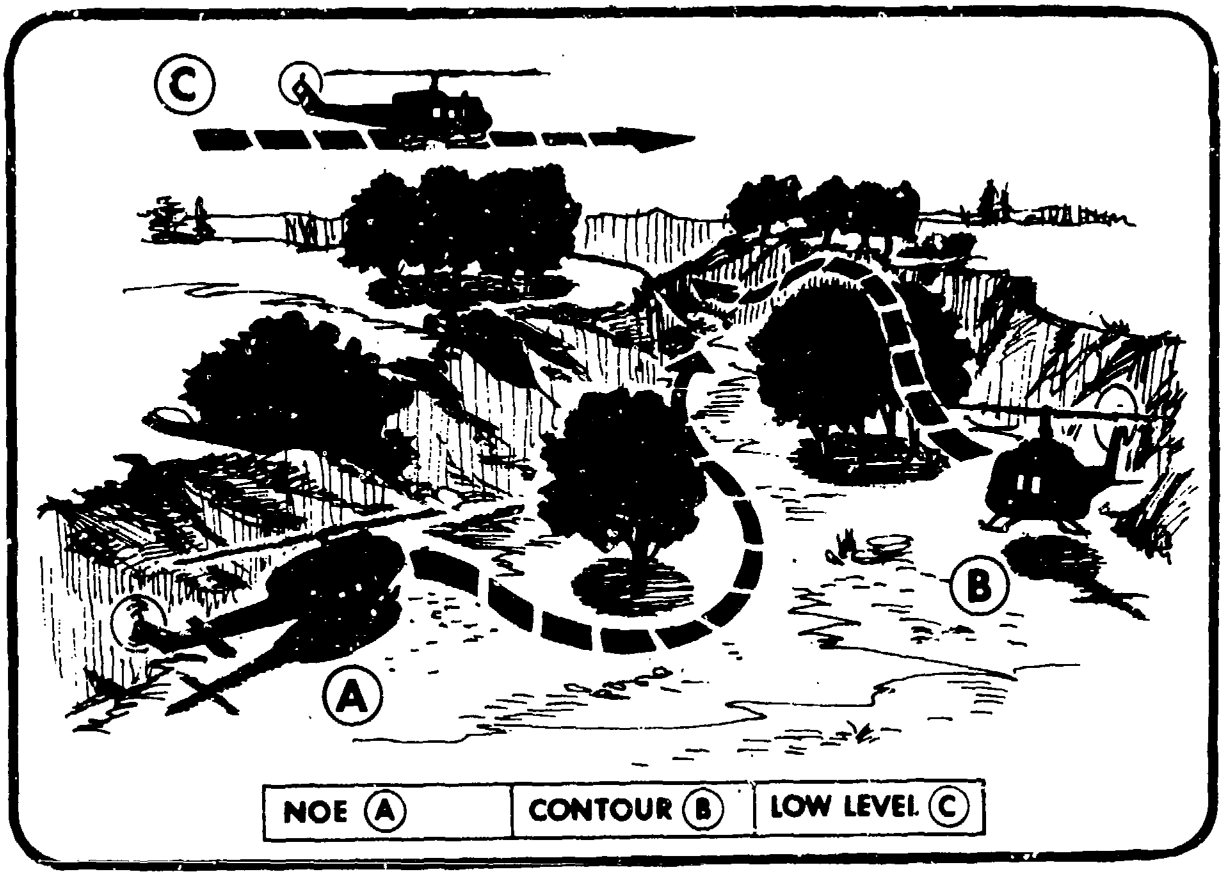

Figure 1. Artist's depiction of terrain flight.

result of the requirements stated in the proposed program of aircrew performance research resulting from this conference, the Army Research Institute developed a map interpretation and terrain analysis course (MITAC) which is a multi-media course of instruction for day navigation (Holman, 1978a). It is currently being taught in the initial entry rotary wing program at the Aviation Center, and is available for distribution through the Army Training Extension Course series.[1]

As a result of experiences with MITAC, the map interpretation and terrain analysis skills for day orientation and navigation are reasonably well understood. However, the question was raised as to how these

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[1]These courses are available in the Training Extension series, TEC Lesson Numbers 902-011-4710 through 4790 and 902-011-4800 through 4831.

skills are related to those required for night unaided vision navigation. Indeed, a similar question might be asked, are there additional skills required that have not been identified for day navigation? To be sure, advances in electronics and navigation aids will be available for night flying activities. These will include the Army night vision goggles, low light level TV (LLTV), and forward looking infrared (FLIR). However, the contingencies when one or more of these elements fails, coupled with the fact that such additional electronic equipment may not be available, underscore the requirement for adequate training for navigation at night with unaided vision.

Purpose

The purpose of this series of experiments on helicopter low-level navigation at night was to gather information critical to the performance and training of tactical night terrain (TNT) flight navigation. The ultimate goal is the development of a program of instruction designed to teach Army aviators to navigate in terrain flight regimes at night with unaided vision. In addition, it was the intent of this series of experiments to establish validated performance measurement for day and night navigation at terrain flight altitudes.

To accomplish the purposes outlined above, two experiments were conducted in-house, augmented by analyses of data under separate contract. The two experiments are reported in this research report and the augmented data analyses are to be reported under separate contractor technical report.

Experiment I

This experiment was designed to develop baseline data of navigational skills, with particular emphasis on ability to identify checkpoints under various conditions. The experimental questions to be answered in this study were:

(1) What types of checkpoints should be used for night navigation at terrain flight altitudes?

(2) What altitude, or altitudes, should be used in the training environment?

(3) What is the effect of prior daylight exposure to a route on the pilot-navigator's ability to navigate the route after dark?

(4) What additional factors should be anticipated in establishing a program of instruction for night terrain flight navigation?

Method

Personnel. Seventeen Army aviators were used as experimental subjects in this test. Fourteen of these aviators were provided by units of the US Army Forces Command (FORSCOM) and three had just completed Rotary Wing pilot training at Fort Rucker. Experience as a helicopter pilot among these subjects ranged from 200 to 3000 hours. Of these 17 subjects, 12 completed all 9 test flights and 5 others completed only 1 to 6 test flights because of weather or operational problems.

Two standardization instructor pilots (SIPs) were attached to ARI from the Army Aviation Center and served as chief pilots for the tests. Two other experienced UH-1 pilots were assigned on temporary duty from FORSCOM to assist the SIPs.

Equipment. Two UH-1H aircraft were used on each test flight. The helicopter used for the low-level flights were equipped initially with a commercial radar altimeter with a single indicator, which was later changed to a military AN/APN-209 radar altimeter with dual indicators. The second helicopter was used for command and control, to maintain a safety check, record data, and help maintain the chief pilots on course when necessary.

From the available maps, an Experimental Air Movement Data Red-Light Night-Use (Prototype 3A) was used. This map is a black and white, negative image, standard Alabama 1:50,000 Series V744-AMD, sheet 3747 K, Petrey Map Sheet.

Procedure. Potential routes of flight were first identified via map study. These corridors of flight were then flight-checked for conformity to safety requirements. From the potential routes, four corridors 12-15 kilometers long and 1 kilometer wide were selected. However, six routes were desired. Due to space limitations in the area of operations, it was decided that two additional routes could be developed by flying two of the four routes in reverse. Each route consisted of an Initial Point, a series of air control points (ACPs), a series of checkpoints (CPs), and a release point. ACPs differed from CPs in that a major change of heading was associated with each ACP. CPs were used to verify location.

Three altitudes were selected in consultation with the chief pilot and were based on his expert judgment. The pilot judged that an altitude of 100 feet above ground level (AGL) was as low as could be safely flown, due to height of trees (75-90 feet tall in some areas) along the routes. He also judged that above 350 feet AGL the flight pattern would be above that which we would consider terrain flight altitude. Therefore, we selected 100 feet, 200 feet, and 350 feet AGL.

A repeated measures design was used to assign subjects to routes and was balanced for altitudes.

Each aviator was requested to report the morning of the first test flight. After a briefing, the aviator was issued a set of nine maps and a list of checkpoint names and map coordiantes for the six test routes. The chief pilot reviewed them and discussed any questions about testing or operational procedures. No attempt was made to control the subject's activities for the time prior to his arrival at the flight operations office that evening. Upon reporting to the flight operations office, standard weather and operations reviews were conducted. This procedure was followed on each of the days of testing.

Since one of the primary factors of this experiment was the development of baseline data of pilot capabilities to identify checkpoints, it was decided that the subjects would be used in a "passive" navigation role. That is, to hold workload to a minimum the navigator was required merely to maintain orientation along the route and to report checkpoints and location on that route as requsted. The chief pilot was responsible for maintaining the aircraft along the centerline of the route. Thus, the navigator had no responsibility to direct the pilot as they proceeded along the route; rather, his only responsibility was to maintain his own orientation and identify checkpoints on the route.

Upon arrival in the area of operations the chief pilot proceeded immediately to the assigned route at the assigned altitude for the day exposure flight. After flying the day route the aircraft was flown to a refueling area where it was refueled and all personnel waited for full darkness. After full darkness, the aircraft then returned to the area of operations and the route previously flown in the daylight was reflown. Following the second flight of that route, the second route of the assigned pair was flown at the same altitude. This sequence of three flights completed one test period. This routine was repeated on subsequent test days and permitted a test of the effect of prior day exposure to the route on the pilot's ability to locate checkpoints on that route. Although there was a confounding effect of exposure due to the fact that the last pair of routes were reversals of the first pair, a minimum of 48 hours elapsed between navigation on routes 1 and 2 and routes 5 and 6.

During the flights the subject was isolated from all communication except that with the chief pilot on a single channel. At the start of each route the test pilot announced the location of the initial point and pointed it out to the subject aviator. He then called the start of the test period. A technical observer recorded the clock time for the start of the test run and noted any special comments regarding visibility made by the chief pilot. At each scheduled air control point, checkpoint or release point in the assigned list on the route, the aviator was required to call the name of the pilot and identify it

precisely or identify it indirectly by naming supporting reference points. If neither of these was possible, he was simply to state that he could not see the point. Three scores were possible for such responses: a correct identification with definite supporting information was scored as 1, a correct identification with some doubt or inadequate supporting information was scored as 1/2, and any identification made prior to or after 250 meters of the designated point was scored 0, as was a failure to call the point. After each identification the subject was told whether his response was correct or incorrect. In instances of disorientation, the subject was given a restart from the last correctly identified point. However, his original score was used for that checkpoint.

At designated locations on each route the chief pilot requested that the subject mark the map across the direction of flight as near as possible to the present location of the aircraft over the route. The time and location for each of these requested mark points along with other appropriate information were recorded by the technical observer.

Along with a standard data collection form, on some flights a cassette tape recorder was used to obtain a recording of cockpit communications in the test aircraft. These recordings were a value to the test personnel in the debriefings and in evaluating test procedures.

Upon completion of the last flight both aircraft returned to the main operations base field. The test pilot or official navigator then conducted a debriefing based on data collected from the maps marked by the subject and from other recorded data.

Probability of identification was the dependent variable in this study. Probabilities were computed as the sum of the correct identifications divided by the possible identifications. Means and variances were obtained and a 90% confidence limit about each mean was computed using the t distribution.

Results and Discussion

The purpose of this test was to determine the effects of altitude and previous exposure of a route on the Army aviator's ability to detect and identify checkpoints; to determine the most useful types of checkpoints for night operations; and to determine any factors which affect night navigation at terrain flight altitudes.

Figure 2 portrays graphically the mean probability of correct checkpoint identification for each of the six routes. Each route is numbered and the D or N indicates whether the route was flown during the day or at night.

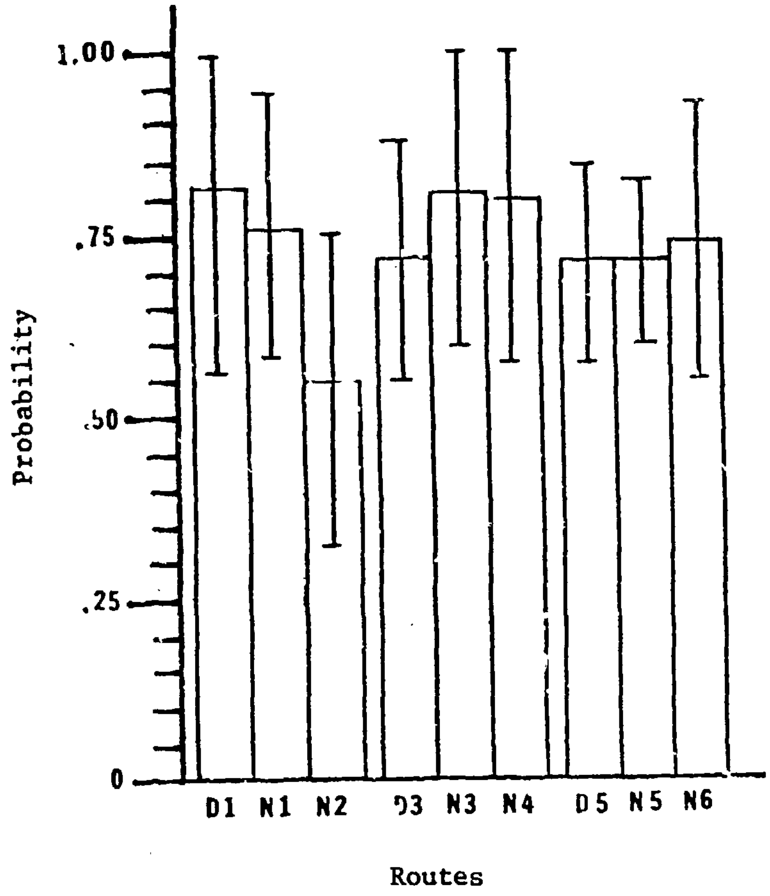

Figure 2. Probability of correct checkpoint identification with 90% confidence limit for each route.

When these six routes were established it was difficult to equate them so as to have six orthogonal routes with similar features. This was due in large measure to the area of operations assigned for this task. Therefore, the chief pilots attempted to equate each of the six routes by selecting equal numbers of air control points and checkpoints of the same or similar features such that there would be an equal number of streams, draws, hilltops, ridges and fields on each of the routes. Consequently, even though Figure 2 illustrates the differences in difficulty of each of the routes and gives some indication of the probability of detecting checkpoints on each of the route for day and night, conclusions based on the figure should be conservative. That is to say, it is not clear from these data how much of the observed differences is due to route difficulty and how much is due to improvement in aviator performances. For example, comparing Day Route 1 and Night Route 1, one expects to see some lowering in probability of correct checkpoint identification. Likewise, comparing the Night Route 1 with Night Route 2, one

would expect an hypothesis to be sustained that it would be easier to identify checkpoints over a route one had previously seen in the daylight hours than the route not having been seen before, so that the results of the first flight over Day Route 1, Night Route 1, and Night Route 2 are as expected. However, when comparing routes 3, 4, 5, and 6, one sees that there is, for practical purposes, no difference in the performance of the navigators in terms of their abilities to correctly identify the checkpoints. This could mean that there was a significant learning experience on the first night's exercise such that the aviators were able to capitalize on experience in their remaining flights. It could also mean that routes 1 and 2 were more difficult or that at least route 2 was the most difficult route. However, it is felt that two factors can explain the results of the comparisons of routes. First, for the most part the aviators seemed to assume that this task was easier than they found it to be in practice. Therefore, their preparation for the first day's flying and particularly their preparation on Night Route 2 was less than desirable. After experiencing the first day's exercises, the observers and the chief pilot did detect more adequate preparation by the subjects on subsequent days. Second, these data are interpreted to mean that there is a significant learning factor on how to locate and distinguish checkpoints.

An overall impression left from examining Figure 2 is that, on the average, the subjects all seemed to perform at roughly the 75% level of probability of correct checkpoint identification. It appears that there is not much benefit to prior daylight exposure to the routes. On the surface this seems to be difficult to accept, or at least it is not what one would predict in such a situation. A second point of note on this figure is that the variability on the day navigation portion seemed to decrease as experience was gained and the variability seemed to decrease on the same route flown after dark. But the variability for each of the night-only routes seems to be maintained at a constant level. The meaning of this is somewhat obscure, but one could conjecture that even though the mean performance of any aviator is apt to remain constant around the 75% level, the variability can be expected to be reduced as a function of practice. The experimental question which needs to be answered for developing a program of instruction is, how can the absolute level of probability of correct checkpoint identification be increased? This particular experiment has heuristic value in generating hypotheses based on the baseline performance which has been observed here.

Figure 3 illustrates the relative difficulties of the various kinds of checkpoints used in this study at the various altitudes.

Perusal of Figure 3 indicates that it is more difficult to identify streams and draws than bridges and fields. It is slightly easier to identify hilltops than streams and draws, but bridges obviously stand

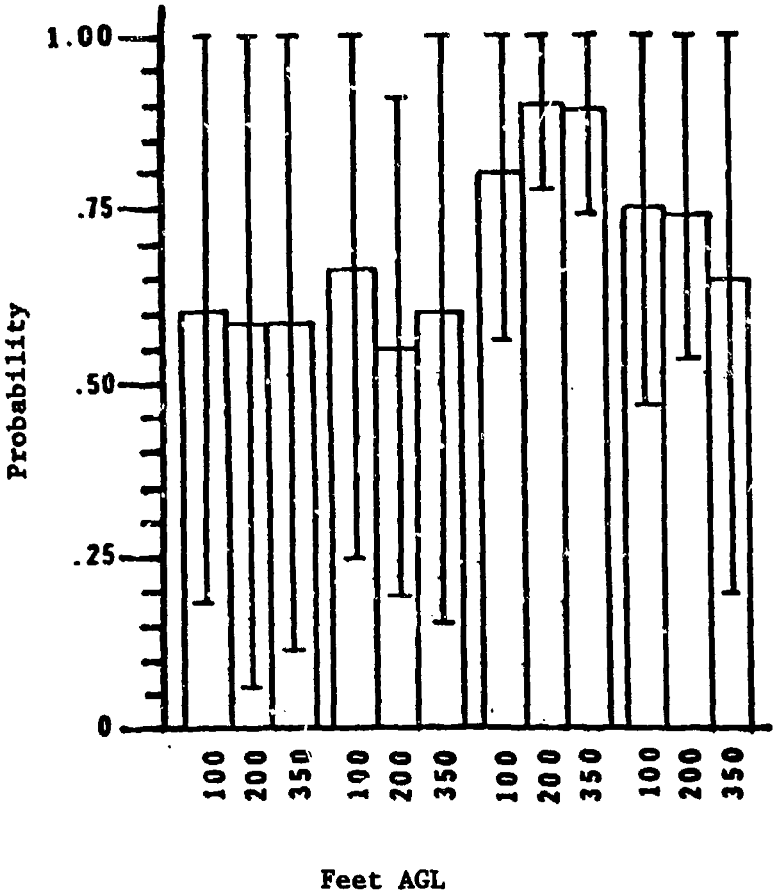

Figure 3. Probability of correct checkpoint identification with 90% confidence limit for altitude and type of checkpoint.

out better than the other checkpoints and are more readily identified. Also, it is striking to note that there is very little variability in correctly identifying bridges, whereas the variability is significantly high for streams and draws, hilltops and fields; and in the latter case particularly at the higher altitude.

In comparing the kinds of checkpoints used for the purpose of determining an optimum altitude for a program of instruction, it appears that there is no advantage to be gained from flying higher than 200 feet AGL. Nor is there much of an advantage to descending lower than that point. This altitude is an important factor in a training environment

because of the elevation of the foliage in the training area of operation. That is, it appears that one could have an adequate clearance from obstacles and still train the initial entry students in checkpoint identification of different kinds of features at an altitude which would be low enough for the purpose of experiencing terrain flight.

Some care should be taken in the finding that bridges are the better checkpoints. The bridges selected for use in this study were on major roadways in most cases. Thus, they were large, open bridges that were easily seen at night. Without a prior knowledge of the area, a similarly reliable selection of bridges might not be possible. For example, bridges on dirt roads were not as easily seen.

On balance, these data show that natural terrain features must be given more emphasis in the training program. The best use of these features appears to be in verification of other checkpoints.

In attempting to gather information which would be useful in establishing a program of instruction of night navigation, weather is a significant factor. Several environmental or meteorological conditions were experienced which were not anticipated and which must be considered in planning an operation of this kind. For example, ground fog typically occurred following spring and summer rainy periods. The fog formed in banks and patches at tree top level, in low lying areas, and in fields. This made for difficulty in distinguishing clearings and fields from the fog patches.

Haze formed during warmer weather in summer and fall. It seemed to be more intense when a temperature inversion was noted near ground level. This problem was often noted in the evening during a period of high barometric pressure when the temperature inversion was observed by the pilots at about 800 to 1500 feet above mean sea level (MSL). On two occasions the temperature inversion was found at about 250 to 300 feet AGL after dark. On these occasions the heavy haze was trapped in the narrow band below 300 feet AGL and it was impossible to fly below this altitude. Even at a higher altitude the only identifiable checkpoints under these conditions were prominent land marks and major fields. The chief pilots were the only pilots capable of identifying most of these prominent checkpoints under conditions of heavy haze. Both types of haze situations occurred when there was little moonlight. Experience with fog suggests that haze will degrade visual capabilities under moonlight conditions because of light diffusion effects.

Sometimes unexpected difficulties arise from totally unanticipated sources. In the early summer hours, the chief pilots also noted that fireflies caused an orientation problem for them. The fireflies seemed to mass near the tree tops and on nights without moonlight the flickering of these fireflies was confused with starlight. This effect resulted in the loss of a visual horizon for both the subjects and the chief pilots.

Airspeed was not included in the design of this experiment as a controlled variable, yet airspeed was found to have an important effect on performance. As the experiment proceeded, the chief pilots observed that several subjects were relying heavily on cockpit instruments. This observation suggested that these aviators were using a time-distance-heading rule and were not relying on visual search of the night environment to locate checkpoints. Large changes in airspeed produced sudden increases in the number of identification errors and frequently resulted in complete disorientation. On the other hand, those subjects who used multiple checkpoints and triangulation methods did not seem to be affected by these airspeed changes. It was also noticed that subjects who reported for the test with a large number of recently accumulated hours in higher speed aircraft such as the AH-1 Cobra had greater difficulty making the initial adjustment to slower speeds.

The lack of a standard phraseology for the cockpit also appeared to hamper the communication between the subject aviator and the chief pilot. Frequently, aviators would wait until the exact location of an assigned point and then call out that point. Often no information as to the location or direction of that point would be given and the chief pilot would then find it necessary to query the subject to determine the correctness of his identification. This resulted in the aviator's losing his orientation on the map or in missing his subsequent checkpoint. Subjects who scored better on these tests were those who could anticipate the checkpoints prior to their occurrence and could lead the checkpoint with information about its location.

In comparing results of the experiment, it was found that those subjects who had little or no practical experience planning or navigating in their operational unit activities, but relied on others in a flight, scored lower on these tests. Obversely, those who had actively participated in planning and navigating exercises scored higher.

Experiment II

The first experiment indicated that natural terrain features, rather than man-made features, should be used for checkpoints and orientation; that there was no advantage in flying at altitudes higher than 200 feet AGL; and that weather information and thorough pre-flight map preparation were important.

Since the first experiment was conducted as a "passive" navigation task, i.e., the navigator merely kept track of his location, the second experiment investigated several factors that could influence the training and performance of an active navigation task during tactical night terrain (TNT) flight. By active navigation we mean that the navigator was required to maintain orientation and issue directions to the pilot for the flight.

Method

Personnel. The subjects were 21 aviators, newly graduated from the Initial Entry Rotary Wing program at Fort Rucker. Each had approximately 225 hours flight time and was qualified to fly nap-of-the-earth. As part of the NOE qualification, each had taken the Map Interpretation and Terrain Analysis Course (MITAC) developed by ARI to teach aviators the special skill required for NOE navigation during the day (Holman, 1978a). It was expected that this training would generalize to the night environment and that none of the subjects would have much difficulty with basic low-level navigation under optimal conditions.

Equipment. The TNT flights were conducted in a UH-1H helicopter equipped with an AN/APN-209 radar altimeter and night flight package. A second UH-1H helicopter was used as a command and control aircraft to maintain a safety watch, to record data and to give the TNT project pilots navigational aid when needed.

Hemispherical light levels were measured before each TNT flight with a Photo Research Corporation Spectra Pritchard Photometer.

Three 1:50,000 scale experimental maps of the Petrey, Alabama area (Series V774, Sheet 3747I) were used. Experimental Air Movement Data (AMD) Red-Light Night-Use Prototype No. 3A was the first and is a black background with white markings topographic line map. The second was the AMD Experimental Prototype No. 1B, a white background colored topographic map. The third was the Experimental Night Photomap No. 1C, a black background, colored, photo-based product developed to specifications written by ARI and the Aviation Center. All maps were developed and supplied by the Defense Mapping Agency Topographic Center.

Dark red goggles (Fluoroscopy-Adaptation Goggles, NSN 6532-00-603-0900) were used to help establish and maintain a state of visual dark adaptation in the project pilots and subject/navigators prior to each TNT mission.

Independent Variables. Each subject was tested on four trials using light level, routes, order of experiencing light level, and map types as independent variables. It was intended that each subject/navigator would navigate each of four TNT routes illuminated by four hemispheric light-level ranges. These ranges were: (a) Dark, 3×10^{-4} ftc and darker; (b) Low, 3×10^{-4} to 3×10^{-3} ftc; (c) Medium, 3×10^{-3} to 1.1×10^{-2} ftc; (d) High, 1.1×10^{-2} ftc and lighter. The light levels were predicted using a procedure described by Holman (1976) and flights were scheduled accordingly.

Four TNT routes were used to control familiarity and to allow the light-levels to be assigned equally to each route.

Ten of the subject/navigators were tested beginning with high light-levels and progressing to lower light-levels. Eleven subject/navigators began testing at low light-levels and progressed to higher light-levels.

To test the three map types, the 21 subjects were divided into three groups of seven subjects. Subjects in each group used only the type map designated for that group.

In addition to the variables discussed above three other factors were evaluated, although no attempt was made to control them. These factors were visibility, dark adaptation, and the pilot.

The most important aspect of weather that affects navigation was felt to be the visibility. Therefore, a 5-point scale of visibility conditions was constructed, with a range from clear to haze and fog. Project pilots and subjects rated these conditions for each flight with 1 meaning clear and 5 meaning visibility was restricted such that no flight was attempted.

It was planned that dark adaptation be maximized by having the pilots and subjects wear red goggles prior to each flight. Pilots were also asked to record inadvertant exposure to bright lights or other interruptions to dark adaptation. These data were coded as a binary factor for analysis.

No attempt was made to systematically control the assignment of subjects and the two project pilots. However, the project pilot was coded and recorded for each flight.

Dependent Variables. Primary measures of terrain flight navigation performance were the frequency and magnitude of flight excursions away from a pre-selected route. At the end of each TNT flight, the project pilot marked on the subject/navigator's map the actual course navigated and the map was retained for analysis. In addition, course deviations were recorded on a debriefing form. From these records, the number of errors per kilometer and mean error magnitude were calculated.

Another measure of navigation performance was the speed a navigator was capable of maintaining. Elapsed time of each TNT flight was recorded by the project pilot on the debriefing form. Since the TNT test routes were of known distances, average speed was easily calculated.

A composite score called TENAV (for terrain navigation) is a measure of terrain navigation performance, derived from MITAC evaluation. It is composed of the number and magnitude of course deviations, speed on route, averaged over the length of the route according to the following equation:

$$TENAV = \frac{\Sigma E^{1.3} + 100^{1.3}}{D \times S^{.8}} \qquad (1)$$

E = A course deviation in meters.

D = Length of the route in kilometers.

S = Average speed on route in minutes.

The basic equation and the exponents in the equation were determined in a magnitude estimation experiment reported by Holman (1977b).

During each TNT test flight the subject/navigators were required to identify predetermined terrain features as checkpoints. The project pilots recorded any checkpoint identification errors on the de-briefing forms.

After each TNT test flight, the project pilot and the subject/navigators filled out de-briefing questionnaires (Appendix A). The questionnaires elicited subjective estimates of the brightness of the night, the difficulty of seeing various types of terrain features, weather conditions, dark adaptation, comfort-fear, pre-flight preparation, and map adequacy. In addition, the project pilot would record elapsed time on route, all course deviation errors and checkpoint identification errors.

Procedure. The subject/navigators were recruited and run in the study in groups of four. Before the TNT test flights, each group was briefed on the purpose of the study and the general procedures to be used. Each was given brief instructions on dark adaptation and the maintenance of night vision, techniques of visual scanning at night, techniques of terrain analysis, lessons learned from the first experiment, and map preparation and interpretation for night navigation. The subjects were then issued the appropriate maps and given the four TNT routes used in the test so that each map could be marked and studied prior to the test flights. Before each night's flight, the TNT mission was briefed, general procedures reviewed, and cockpit and communication procedures unique to the test reviewed.

Each test flight began with the project pilots flying the TNT helicopter and the cover helicopter from Fort Rucker to Troy Municipal Airport where the aircraft were refueled and the aviators waited for the predetermined time to perform each TNT flight. During this time, red goggles were usually worn to enhance dark adaptation.

At the appropriate time, both helicopters would be flown to the area in which the four TNT routes were located and the cover helicopter would land in a convenient landing zone. The hemispheric light level data were taken in the landing zone and the flight continued.

The project pilot in the TNT aircraft flew the subject/navigator to the starting point of the TNT route, insured that the subject/navigator was oriented and began the test run by overflying the starting point in the direction of the route at 150 feet AGL. The subject/navigator began navigating at this point and the project pilot flew the aircraft according to the navigator's directions. The subject/navigator was asked to direct the aircraft over the preselected route as accurately as possible and at as high a speed as was consistent with accuracy and safety. During the TNT test flight, the subject/navigator identified the required checkpoints along the route. If the subject/navigator directed the flight off course by 1,000m, the project pilot returned to the course, oriented the subject/navigator and continued the flight. The TNT flight ended when the helicopter flew over the end of the route.

Both aircraft then returned to Troy Municipal Airport for fuel, picked up the second subject and continued the test. In this manner, each subject navigated each of the four TNT routes, one route per night, under varying conditions of moon illumination.

After each flight, the project pilot marked on the subject's map the actual route flown. Then both the pilot and the navigator filled out the de-briefing questionnaire.

Results and Comments

The data were transcribed from the subject/navigators' maps, de-briefing forms and the pilots' de-briefing forms and coded for analysis by computer. Each dependent variable was subjected to a multiple stepwise linear regression against all of the measured independent and uncontrolled variables (Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975; Kerlinger & Pedhazur, 1973). All independent variables that accounted for 1% or more of the variance as indicated by the square of the change in the multiple correlation (ΔR^2) at each step were included. Those variables whose F to enter had a probability, p, greater than 0.1 were not considered statistically significant.

Results of the multiple regressions on the variables of interest are presented in tables. Variables are entered in the tables in order according to the proportion of variance for which they account. The column ΔR^2 in each table shows the proportion of variance for each variable and the column cumulative R^2, accumulates the variance accounted for as the variables were added.

The frequency of error is one of the primary measures of navigation performance. In this test all deviations of the aircraft of 100 meters or more from the selected course were considered errors. Table 1 is a summary of the regression analysis predicting errors per kilometer as a function of the variables listed. The listed variables accounted for 48% of the variance in the data. The analysis showed that the map types

used in this test account for more of the variance (20%) than any other variable. Map 3, the Experimental Night Photomap accounted fro 17% of this variance and its negative simple correlation means that Map 3 was associated with a reduction in the frequency of error.

Table 1

MULTIPLE REGRESSION SUMMARY TABLE
NUMBER OF ERRORS PER KILOMETER

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Map 3	16.8	.0001	.41	.17	.17	-.41
2	Pilot	12.3	.001	.52	.11	.28	-.38
3	Route 1	11.6	.001	.61	.09	.37	.31
4	Visibility	4.3	.041	.64	.03	.40	.25
5	Map 2	4.3	.042	.66	.03	.43	.04
6	Trial 4	3.2	.079	.67	.03	.46	-.10
7	Route 4	1.6	.206	.68	.01	.47	-.21
8	Other Var.			.69	.01	.48	

The next largest amount of variance is attributed to the project pilots who flew the subject/navigators during the tests. The two pilots were asked to behave toward the task and subjects as nearly identical to each other as possible. However, there were, apparently, differences in their behavior since pilots were a source of 11% of the variance. These data point out the importance of the pilot in contributing to navigator accuracy.

Two TNT routes used for the test also account for a portion (10%) of the variance. Route 1 was the most difficult, accounting for 9% of the variance.

Visibility accounted for 3% of the variance in frequency of error. Visibility is a much more important variable than is indicated by this analysis of error frequency and more will be said about this later.

The next most significant variable was Trial 4, the last trial. It accounted for 3% of the variance and the negative r means that error frequency was lower on the subjects' last trial.

Finally, we were interested to note that the two variables thought most relevant to night flying, viz, light level and dark adaptation, were not related to frequency of error.

Figure 4 displays graphically the changes in frequency of error associated with the three map types and with four levels of decreasing visibility. Given the best of weather conditions, those with a rating of 1, and the superior map (Map 3), the regression equation would predict only one error of more than 100m over a 15 km TNT route. At the other extreme, given poor visibility (rated as 4) and the inferior map (Map 1), the predicted number of errors would be four.

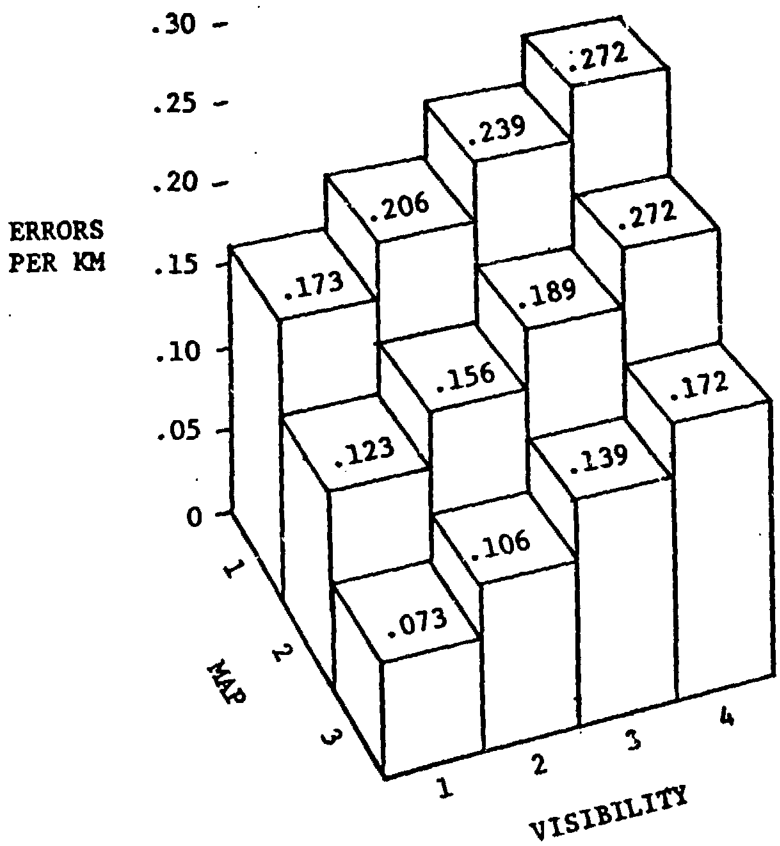

Figure 4. Navigation Errors Per Kilometer as a function of Map Type and Visibility during TNT flight.

Table 2 is a summary of the analysis predicting mean error magnitude as a function of the variables listed. We were able to account for 24% of the variance.

Each course deviation of 100m or more was recorded in terms of the distance in meters the aircraft traveled from the selected route. This measure was not allowed to vary freely because of safety considerations. For a test run, the project pilot was instructed to stop the subject/navigator when the subject guided the aircraft 1000m off course, return to course, orient the subject and resume the test. As was the case with error frequency, the map style accounted for more of the variance (6%) than did any other variable. Again, the negative simple correlation (r) indicates that Map 3 can be associated with a reduction in error magnitude. Subjects increased error magnitude on Trial 4, unlike the decrease in error frequency we observed on Trial 4. Perhaps this was due to the increased speeds used as the subjects developed experience. Route 1 was associated with smaller errors as indicated by the negative $\underline{r}$, and accounted for 4% of the variance. Another 9% of the variance was attributed to several other variables listed but none was statistically significant. ($\alpha < .10$).

Table 2

MULTIPLE REGRESSION SUMMARY TABLE
MEAN ERROR MAGNITUDE

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Map 3	5.2	.026	.24	.06	.06	-.24
2	Trial 4	4.6	.034	.33	.05	.11	.22
3	Route 1	3.4	.067	.38	.04	.15	.19
4	Light Lvl	2.1	.152	.41	.02	.17	.14
5	Trial 2	1.4	.246	.43	.01	.18	-.17
6	Order	1.3	.264	.44	.02	.20	-.13
7	Dark Adpt	2.0	.158	.47	.02	.22	-.17
8	Route 3	1.1	.291	.48	.01	.23	.12
9	Other Var.			.49	.01	.24	

Another primary measure of low level navigation performance is the speed with which the navigator guides the helicopter over a route. Table 3 is a summary of the analysis predicting speed as a function of the variables listed in the table. We were able to account for 44% of the variance in the analysis of speed.

Table 3

MULTIPLE REGRESSION SUMMARY TABLE
SPEED

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Order	12.6	.001	.36	.13	.13	.36
2	Dark Adpt	10.3	.002	.48	.10	.23	.18
3	Light Lvl	10.0	.002	.56	.09	.32	.36
4	Trial 1	5.7	.019	.60	.04	.36	-.21
5	Map 1	3.3	.072	.62	.03	.39	-.24
6	Visibility	3.7	.059	.64	.03	.42	-.31
7	Trial 4	1.1	.288	.65	.01	.43	.13
8	Other Var.			.66	.01	.44	

The variable in the regression analysis that accounted for the most variance (13%) in the speed data was the order in which the subject/navigators were exposed to different light levels. Subjects who started with low light-level conditions and finished under high light levels were able to attain higher average speeds on the routes than those who began in high light levels. We believe the reason for this is an interaction which occurs with learning and light level. Those who began in high light levels flew slower as they gained experience. Experience should allow them to increase speed but this was offset by the necessity of slowing down in the lower light levels which they experienced in their later trials.

The second most important variable was the subject/navigators dark adaptation. This accounted for 10% of the variance. The better dark adapted subjects navigated faster.

The third important variable was the ambient light level. Light level was responsible for 9% of the variance and increased light levels are associated with higher speeds.

The fourth most important variable was practice. The trial variable accounted for 5% of the variance. The negative correlation associated with Trial 1 indicates that speeds were lower during Trial 1 and increased with experience.

The fifth important variable was map style. Map 1 accounted for 3% of the variance and the negative correlation indicates that slower speeds are associated with this black and white prototype.

The last significant variable was visibility, accounting for 3% of the variance. The clearest conditions resulted in the highest speeds.

Figure 5 illustrates the relation between dark adaptation, light level and speed. The figure illustrates that dark adaptation is responsible for a difference in speed of approximately 12 km/hr. A change from a low light level to a high light level (the difference between no moon and full moon) is also responsible for approximately 12 km/hr. This means that an aviator can navigate on moonless nights if well dark adapted as quickly as on brightly moonlit nights if poorly adapted.

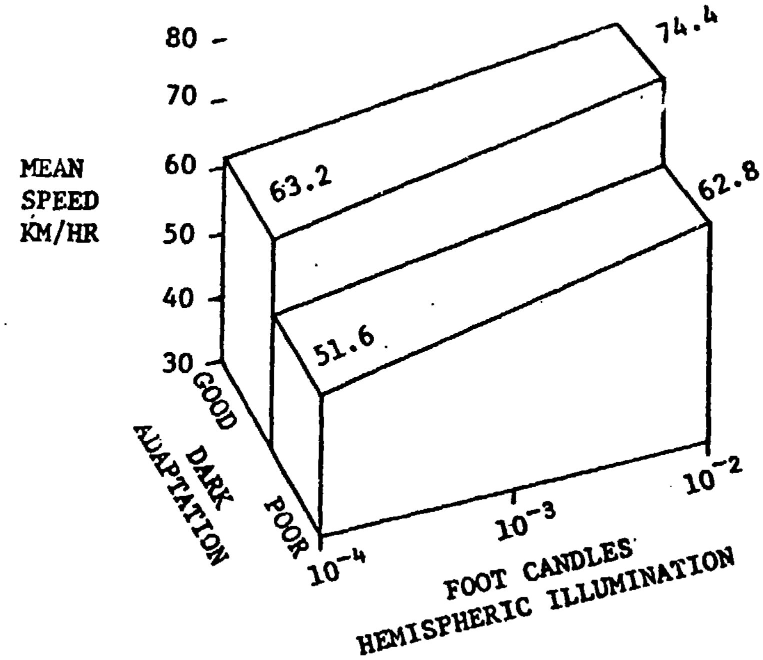

Figure 5. Speed of navigation as a function of Dark Adaptation and Hemispheric Illumination during TNT flight.

A multiple regression of the composite score, TENAV, on the variables of interest was conducted. Due to the skewed nature of the distribution of TENAV scores, the regression analysis was performed on the log transform of these data. A summary of the analysis is presented in Table 4. Since TENAV scores are composite scores based on errors and speeds averaged over the length of any particular route, the smaller the TENAV score, the better the navigation performance. In daylight NOE flights, a TENAV score of 1.0 or lower is considered superior. Scores of 2.0 to 4.0 are good and scores from 5.0 to 10.0 are considered acceptable (Holman, 1978b). In the night environment similar standards have not been estimated but in the current data it appears that these same standards are appropriate.

Table 4

MULTIPLE REGRESSION SUMMARY TABLE
LOG TENAV

Step	Variable Entered	F to Enter	p <	Multiple R	ΔR^2	Cumulative R^2	r
1	Map 2	16.5	.0001	.41	.17	.17	-.41
2	Visibility	12.7	.001	.53	.11	.28	.37
3	Pilot	7.0	.010	.58	.06	.34	.29
4	Map 1	3.4	.067	.60	.03	.37	.28
5	Dark Adpt	2.9	.091	.62	.02	.39	.30
6	Trial 1	2.8	.099	.64	.02	.41	.08
7	Order	1.8	.182	.65	.01	.42	.28
8	Other Var.			.66	.01	.43	

In using TENAV as a measure of performance there were some minor rearrangements in the order of importance of the predictor variables. However, map style was still the prominent variable, accounting for 20% of the variance, with Map 3 again demonstrating its utility as the better map. The negative correlation indicated for Map 3 is interpreted to mean Map 3 users had lower TENAV scores and better performance. Contributions of the remaining significant variables can be noted as they were entered on the list by the computer program.

The next most significant variable was the visibility condition which accounted for 11% of the variance. The third variable was the pilot, which accounted for 6% of the variance. As with error rate, this analysis points out the importance of the navigator-pilot team, even when the pilot is trying to fly in a standardized manner and not actively aid the navigator. The last significant variable was dark adaptation which accounted for 2% of the variance. It should be noted that light level was not a significant variable in this analysis, which is somewhat contrary to the conventional wisdom. In all, these predictor variables accounted for 48% of the variance.

Figures 6a and b illustrates the relations between the three major variables in this analysis and TENAV scores. Figure 6a depicts the influence of map style and visibility on performance and Figure 6b depicts the effects of dark adaptation and visibility on performance.

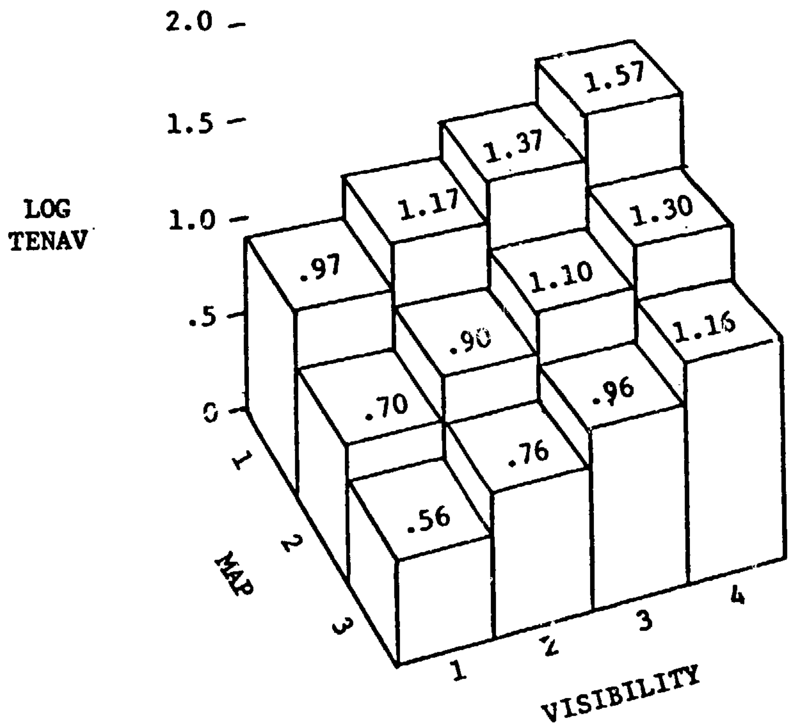

Figure 6a. Log TENAV scores as a function of Map Type and Visibility during TNT flight.

Figure 6a assumes good dark adaptation and Figure 6b assumes the use of Map 2 as an arbitrary middle value. It is obvious from these figures that TNT flight should be conducted with the best maps available, with great care taken to insure good dark adaptation, and under the clearest visibility conditions possible.

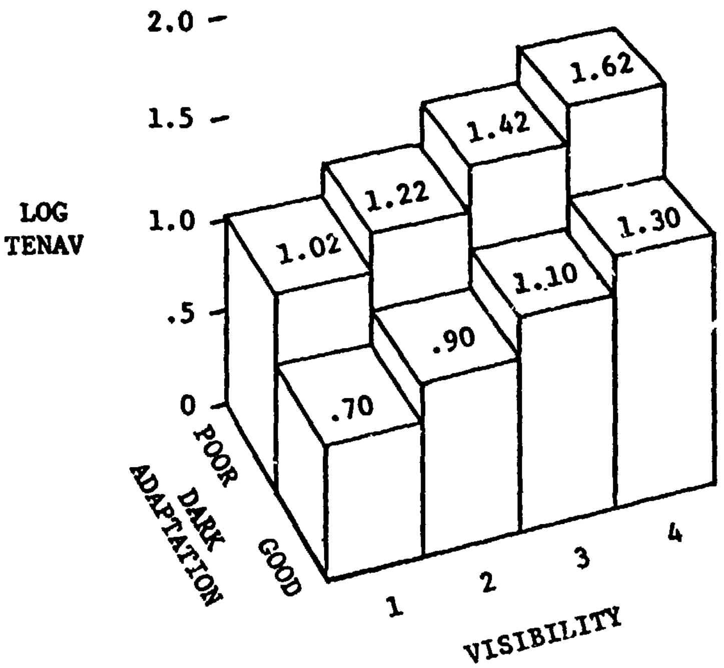

Figure 6b. Log TENAV scores as a function of Dark Adaptation and Visibility during TNT flight.

Table 5 shows the results of the regression analysis of field identification as a function of the variables of interest. The overall probability of identifying a field as a specific checkpoint was .75, based on a ratio of opportunities to identify fields with field identifications. Table 5 shows that 9% of the variance in the data was accounted for by the order the subject/navigators were exposed to the different light levels. The order that resulted in higher probabilities of detection was the case in which the subjects began Flight 1 in dark conditions and subsequent flights were in progressively higher light levels. Routes was a significant variable due to different numbers of fields along each route. Maps accounted for 4% of the variance with Map 2 identified as a good map for field identification.

Table 5

MULTIPLE REGRESSION SUMMARY TABLE
IDENTIFYING FIELDS AS CHECKPOINTS

Step	Variable Entered	F to Enter	$p<$	Multiple R	ΔR^2	Cumulative R^2	r
1	Order	8.1	.006	.30	.09	.09	.30
2	Route 3	3.7	.057	.36	.04	.13	.20
3	Map 2	3.8	.055	.41	.04	.17	.21
4	Trial 1	1.0	.307	.42	.01	.18	.09
5	Light Lvl	.6	.425	.43	.01	.19	-.14
6	Other Var.			.45	.02	.21	
7	Subjects	1.2	.300	.60	.15	.36	

Table 6 shows the analysis of correctly identifying hills as checkpoints as a function of the variables entered. The overall probability of identifying a hill as a checkpoint was .76. Table 6 shows that the pilot accounted for 8% of the variance in the hill checkpoint data. Routes were another significant variable due to different numbers of hills on each route. Maps were the next significant variable accounting for 4% of the variance. Map 3, the Night Photo Map, was best. Visibility was another significant variable along with experience as indicated by trials.

Table 7 shows the analysis of ridge identification as a function of the variables entered. The overall probability of identifying a ridge as a checkpoint was .82. Routes again accounted for a significant portion (14%) of the variance due to different numbers of ridges on each route. As was the case with hills, the Pilot and Map variables were also significant.

Table 8 shows the analysis of pond identification as a function of the variables entered. The overall probability of identifying a pond as a checkpoint was .81. As with the other checkpoints, the specific routes accounted for a large portion (30%) of the variance. Ponds was the only checkpoint variable affected by light level, which accounted for 2% of the variance.

Table 6

MULTIPLE REGRESSION SUMMARY TABLE
IDENTIFYING HILLS AS CHECKPOINTS

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Pilot	7.2	.009	.28	.08	.08	.28
2	Route 2	4.9	.029	.36	.05	.13	.21
3	Map 3	3.1	.083	.41	.04	.17	.21
4	Visibility	3.4	.067	.45	.03	.20	.16
5	Trial 1	3.8	.056	.49	.04	.24	.19
6	Trial 4	2.2	.138	.51	.02	.26	.11
7	Light Lvl	2.1	.152	.53	.02	.28	-.10
8	Other Var.			.55	.02	.30	

Table 7

MULTIPLE REGRESSION SUMMARY TABLE
IDENTIFYING RIDGES AS CHECKPOINTS

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Route 4	7.4	.008	.29	.08	[illegible]	-.29
2	Route 2	5.6	.020	.38	.06	.14	-.13
3	Pilot	4.6	.034	.43	.05	.19	.25
4	Map 3	3.1	.081	.47	.03	.22	.20
5	Visibility	1.2	.280	.48	.01	.23	-.09
6	Other Var.			.49	.01	.24	

Table 8

MULTIPLE REGRESSION SUMMARY TABLE
IDENTIFYING PONDS AS CHECKPOINTS

tep	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Route 3	25.9	.0001	.49	.24	.24	.49
2	Route 4	7.1	.009	.55	.06	.30	.07
3	Light Lvl	2.9	.092	.57	.02	.32	-.15
4	Map 2	1.7	.190	.58	.02	.34	.12
5	Other Var.			.60	.02	.36	

Table 9 shows the analysis of pilots' estimates of light level as a function of the variables of interest. Table 9 shows that 78% of the variance in the pilots' estimates of night light levels was accounted for by the actual light levels as measured by photometer. It must be emphasized that these estimates were not made solely on the basis of perceived brightness. The pilots also knew the percent moon visible and could estimate the moon's height above the horizon and could use this knowledge to help infer light levels.

Table 10 presents a summary of the analysis of pilots' estimates of comfort/fear as a function of the variables. Table 10 shows that 24% of the variance in these data is accounted for by the map variable. This seemed peculiar but the pilots explained this by saying that they were made uncomfortable by the subject/navigator's poorer performance, which seemed to be related to using Maps 1 and 2. Light level was the second significant variable, accounting for 12% of the variance. It was clear that the pilots were more comfortable in higher light levels where they could see obstacles better and they felt the navigators were performing better. The same can be said for dark adaptation which accounted for 4% of the variance. Order of flights also accounted for 4% of the variance with the light-to-dark-order associated with higher levels of discomfort.

Table 9

MULTIPLE REGRESSION SUMMARY TABLE
PILOTS' SUBJECTIVE ESTIMATE OF LIGHT LEVEL

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Light Lvl	285.2	.0001	.88	.78	.78	.88
2	Map 1	8.2	.005	.89	.02	.80	.03
3	Pilot	4.8	.032	.90	.01	.81	-.20
4	Other Var.			.91	.03	.84	

Table 10

MULTIPLE REGRESSION SUMMARY TABLE
PILOTS' ESTIMATE OF COMFORT/FEAR

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Map 2	21.0	.0001	.45	.20	.20	.45
2	Light Lvl	14.3	.0001	.57	.12	.32	-.34
3	Order	5.5	.022	.60	.04	.36	.28
4	Dark Adpt	5.3	.024	.64	.04	.40	.26
5	Map 3	4.6	.036	.66	.04	.44	-.20
6	Trial 4	3.7	.057	.68	.02	.46	.15
7	Trial 3	1.1	.301	.69	.01	.47	.01
8	Other Var.			.70	.02	.49	

Table 11 is a summary of the analysis of subject/navigator estimate of light level as a function of the variables. Table 11 shows that 77% of the variance in the subject/navigators' estimate of night light levels was accounted for by the actual light levels as measured by photometer. As in the case of the pilots' estimates, the subjects had other sources of information available including the project pilots.

Visibility accounted for 2% of the variance. This percentage was lower than expected based on conversations with the project pilots and navigators. Anecdotally, it seemed that they would claim one night was much darker than another when the photometer readings were the same and that this claim was actually due to reduced visibility in haze or light fog.

Table 11

MULTIPLE REGRESSION SUMMARY TABLE
NAVIGATORS' SUBJECTIVE ESTIMATE OF LIGHT LEVEL

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Light Lvl	276.0	.0001	.88	.77	.77	.88
2	Visibility	7.6	.007	.89	.02	.79	-.28
3	Map 1	3.3	.072	.89	.01	.80	.02
4	Other Var.			.90	.02	.82	

Table 12 summarizes the analysis of navigators' estimates of comfort/fear as a function of the variables entered. Table 12 shows that 14% of the variance in these data was accounted for by the map variable. Experience, as reflected in trial number, accounted for another 7% with less experience associated with higher levels of fear. Dark adaptation accounted for 6% of the variance with good adaptation associated with less fear. Order accounted for another 5% with dark to light order associated with higher levels of fear. Routes accounted for 4% indicating that two of the routes were more fear provoking than the other two.

Table 12

MULTIPLE REGRESSION SUMMARY TABLE
NAVIGATORS' ESTIMATE OF COMFORT/FEAR

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Map 2	12.9	.001	.37	.14	.14	.37
2	Trial 1	5.9	.017	.44	.05	.19	24
3	Dark Adpt	6.1	.016	.50	.06	.25	.34
4	Order	5.3	.024	.55	.05	.30	.13
5	Route 3	3.8	.054	.57	.03	.33	.11
6	Trial 2	1.6	.204	.59	.02	.35	.01
7	Route 2	1.4	.238	.60	.01	.36	.08
8	Light Lvl	1.2	.266	.61	.01	.37	-.16
9				.61	.00	.37	

Table 13 summarizes navigators' estimates of map interpretability as a function of the variables entered. Table 13 shows that 7% of the variance in the subject/navigators' estimate of the ease of interpreting the map inflight was accounted for by the map styles. The daylight Air Movement Data Prototype was judged easiest to interpret. This result is especially interesting in view of the performance data which indicates that the Experimental Night Photomap was superior to the others. This disagreement between the performance data and the ease of interpreting opinion data should serve as a warning against accepting opinion and preferences in evaluating a map format, or other device, and as a reminder that performance data are required. The only other significant variable was Trial 1, which accounted for 3% of the variance. On the first trial the subject/navigators reported that the maps were harder to interpret than on subsequent trials.

Table 14 is a summary of the analysis of navigators' estimates of ease of seeing fields and streams as a function of the variables entered. Table 14 shows that 41% of the variance in these data is accounted for

Table 13

MULTIPLE REGRESSION SUMMARY TABLE
NAVIGATORS' ESTIMATE OF EASE OF INTERPRETING THE MAP

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Map 2	5.3	.023	.25	.06	.06	.25
2	Trial 1	2.8	.099	.30	.03	.09	-.18
3	Light Lvl	2.0	.162	.34	.02	.11	.16
4	Route 4	1.3	.260	.36	.02	.13	-.12
5	Visibility	1.4	.237	.38	.01	.14	-.03
6	Map 3	.9	.342	.39	.01	.15	-.03
7	Order	1.3	.257	.41	.02	.17	.02
8	Other Var.			.43	.01	.18	

Table 14

MULTIPLE REGRESSION SUMMARY TABLE
NAVIGATORS' ESTIMATE OF EASE OF SEEING FIELDS AND STREAMS

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Light Lvl	56.7	.0001	.64	.41	.41	.64
2	Trial 1	8.6	.004	.68	.05	.46	-.27
3	Visibility	3.1	.082	.70	.02	.48	-.21
4	Dark Adpt	2.1	.152	.71	.02	.50	-.09
5	Other Var.			.72	.01	.51	
6	Subjects	2.1	.025	.84	.19	.70	

by Light Level. The brighter the night was, the easier it was reported to see fields or streams. Experience (Trial 1) accounted for 5% and visibility for 2%. The correlation between the reported ease of seeing fields and the probability of correctly identifying checkpoints that were fields was $\underline{r}$ (83) = .20, $\underline{p} < 0.1$. Even though fields and streams were reported more difficult to see at the low light levels, checkpoint identification and accuracy of navigation did not suffer very much but the navigator/subjects traversed the routes slower. The only other significant variable was Subjects, which accounted for 19% of the variance. The tables are set up by the analysis with the most significant variables entered first and others in order of significance. Since the SPSS does not treat a within Subjects design, Subjects was treated as an additional variable and the program was instructed to consider Subjects after the other variables.

Table 15 summarizes the analysis of the navigators' estimates of the ease with which they could see fields and streams as a function of the variables entered. The variables light level, the first trial, and estimated visibility, were significant predictors of navigators' estimates. As noted, light level had a significant effect on estimates of ease of seeing these objects, accounting for 41% of the variance. The navigators obviously believed that light level affected their ability to see checkpoints such as hills and ridges, but performance measures indicated that the only factor affected by light level was the speed at which a course was traversed. (See Table 3).

Table 16 summarizes the analysis of the navigators' estimates of ease of seeing roads and bridges as a function of the variables entered. Again, light level is important as a predictor of navigator estimates, but, as was the case with the comments about Table 15, light level is judged to be important yet performance is sustained, except in the case of speed. And, Subjects proved to be a significant source of variance as a predictor.

General Discussion

Our fundamental task was to obtain data on which to build a program of instruction for tactical night terrain flight navigation using unaided vision. There is much information extant on this subject in the form of conventional wisdom, but there was little documentation. Consequently, we elected to use a building block approach with a series of experiments, and to set liberal criteria when testing for significance, so as not to preclude any variable relevant to the task of night navigation.

The first experiment was a probe in which the test pilots literally tested their abilities to cope with such requirements as flying and navigating at very low altitudes at night. It was in this fashion that the actual techniques for data collection were developed.

Table 15

MULTIPLE REGRESSION SUMMARY TABLE
NAVIGATORS' ESTIMATE OF EASE OF SEEING HILLS AND RIDGES

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Light Lvl	56.2	.0001	.64	.41	.41	.64
2	Route 1	8.3	.005	.68	.05	.46	-.26
3	Trial 1	3.4	.068	.70	.02	.48	-.19
4	Map 3	2.2	.142	.71	.02	.50	-.05
5	Route 3	2.1	.151	.72	.01	.51	.19
6	Visibility	1.6	.206	.72	.01	.52	-.19
7	Other Var.			.73	.01	.53	

Table 16

MULTIPLE REGRESSION SUMMARY TABLE
NAVIGATORS' ESTIMATE OF EASE OF SEEING ROADS AND BRIDGES

Step	Variable Entered	F to Enter	p<	Multiple R	ΔR^2	Cumulative R^2	r
1	Light Lvl	37.2	.0001	.56	.31	.31	.56
2	Trial 1	3.9	.053	.59	.03	.34	-.20
3	Pilot	3.8	.055	.61	.03	.37	-.24
4	Order	2.8	.098	.63	.02	.39	-.26
5	Route 4	1.7	.190	.64	.02	.41	-.10
6	Map 3	1.2	.267	.65	.01	.42	.19
7	Other Var.			.66	.01	.43	
8	Subjects	2.4	.005	.83	.26	.69	

In general, the first experiment verified conclusions from day navigation research. Natural terrain features, and particularly those with vertical development, were more desirable as checkpoints. Furthermore, adequate planning of the flight and flying the plan proved to be a "tried and true" axiom.

Thus, the type checkpoints suitable for navigation in a passive task were tested in the next experiment at what was considered a suitable flight altitude which could yield adequate training with safety.

The results of the second experiment corroborated what we learned from the first experiment; what was known about terrain flight navigation from experience; what is common knowledge about the function of the human eye, ergo human performance, in low illumination environments; and provided information concerning the effects on performance of map type, level of illumination, order of training, visibility effects, and experience.

The most important determiner of navigation performance, considered from the standpoint of error magnitude, error frequency, or TENAV was the type of map used. While the Experimental Night Photomap No. 1C was associated with better navigation performance, the likelihood that it will be printed and issued is low. It is more likely that a map similar to the Air Movement Data (AMD) Experimental Prototype No. 1B will be printed and issued. Our data indicated that, though the 1B was less satisfactory than the 1C, it would be a satisfactory map for use at night. This map was also judged to be the easiest to read under night flight conditions. There are indications also that, as all maps are revised for use, some air movement data will be included and red light inks will be used to preclude bleaching of color when red lights are used at night.

We used light level in two ways in this experiment; controlling for light level and for order of experiencing light level. The conventional wisdom has always held that light level was the most significant factor to be considered in night operations. But, we found that speed of traversing a route was the only measure affected by light level. Frequency or magnitude of error were not significantly affected by light level. We interpret this in a rather simplistic fashion; namely, that as illumination is reduced navigators will request that the pilots fly slower so that checkpoints can be seen, since at these light levels checkpoint identification requires peripheral (rod) vision which takes more time.

There appears to be an interactive effect between light level, the order the subjects experienced the light level (low-to-high versus high-to-low), and learning. When the subjects were exposed to different light levels speed was affected. Those who were exposed to low light levels first were able to fly faster under high light levels. But those

who flew in high light levels first flew slower in these conditions and in the low light level condition. We believe this points to experience as a factor to be considered. Defining experience as number of trials, we found error frequency and magnitude, speed, TENAV, and some checkpoint identifications were affected. As the subjects gained experience through practice, errors were reduced, speed was increased, checkpoints were identified and self-reported confidence was increased as well as was the reported ease of seeing and reading the maps and seeing the terrain features. Thus, pilots who gained experience in low light levels were able to use both the experience gained and the higher light levels to increase speed. But those who gained experience in high light levels first, found that this experience was counteracted, as it were, by the requirement to reduce speed in lower light levels in order to hold errors to a minimum.

The project pilots who flew the missions for the navigators were a source of variation in the data in spite of attempts to standardize and control their behavior. In some cases they significantly affected error frequency, TENAV, and checkpoint identification. We do not know if differences in their behavior led to improved navigator performance but it can be concluded, with some degree of assurance, that the ability to function as a pilot-navigator team is important and there are probably benefits to be gained from conducting crew/team training in navigation.

As stated previously, it was assumed that light level was the important factor in night navigation performance. However, Experiment II showed that restriction to visibility was a greater determiner of performance than light level. It significantly affected error frequency, speed, and TENAV. It also affected checkpoint identification ability and subjects' estimates of light level--reduced visibility conditions were perceived as darker. Furthermore, this condition is one which cannot be trained for, nor can the eye adapt in any way to improve its performance (outside of some evolutionary process perhaps) as it can in the case of dark adaptation. In comparing restrictions to visibility with light level it should be sufficient to say that no mission was terminated because of darkness but two missions were aborted due to restrictions to visibility. It should be noted that such restrictions to visibility are not limited to clouds or fog, but include haze, smog, smaze, or any similar condition involving moisture-laden air and condensation nuclei.

We attempted to control for dark adaptation in a "passive" way; encouraging each subject to wear red goggles while waiting for the flight periods. We had subjects estimate their use of red goggles. The results of comparisons of estimates with performance were striking. Better dark adaptation was associated with better performance as measured by speed and TENAV. Those subjects and pilots who reported low levels of dark adaptation also reported higher levels of subjective discomfort or reduced confidence on the routes.

<u>Conclusions</u>

1. Tactical terrain flight navigation with unaided vision can be performed at all light levels likely to be experienced.

2. Tactical night terrain flight navigation can be trained; performance improves with practice.

3. 150 feet above ground level is a good altitude to train navigation because it provides adequate training with a safety margin.

4. Natural terrain features, especially those with vertical development, make better checkpoint cues.

5. It is imperative to maximize dark adaptation to attain the best possible navigation performance.

6. Restrictions to visibility in the operating area must be considered; restrictions significantly reduce navigation performance.

7. A standard 1:50,000 tactical map is acceptable if it is printed with red light-readable inks and includes air movement data.

8. Preflight planning and map study and preparation are essential; "Plan the flight - fly the plan."

9. Training for navigation as a crew or team can improve performance.

10. A standardized intra-cockpit phraseology would enhance crew performance.

11. A radar altimeter is deemed essential to tactical night terrain flight navigation training.

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